ESTIMATES OF JUVENILE SOCKEYE SALMON ABUNDANCE IN SKILAK AND KENAI LAKES, ALASKA, BY USE OF SPLIT-BEAM HYDROACOUSTIC TECHNIQUES, SEPTEMBER 2002

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Regional Information Report[1] No. 2A03-03

Alaska Department of Fish and Game
Division of Commercial Fisheries
333 Raspberry Road
Anchorage, Alaska 99518

January 2003

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ACKNOWLEDGEMENTS

The authors thank Bill Glick, Stan Walker, Dave Westerman, and Mark Willette, of ADF&G for assistance with field operations. Much thanks to Don Degan and Anna-Maria Mueller of Aquacoustics Inc. for GIS assistance and to Sandi Seagren for help in preparing this report.

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ABSTRACT

Estimates of population size and age composition of juvenile sockeye salmon fry in Skilak and Kenai lakes, which produce most of the sockeye salmon in Upper Cook Inlet, are critical data used to assess freshwater survival and forecast adult returns. While there is widespread consensus that interannual variability in salmon survival is strongly related to changes in ocean-climate conditions, growth and survival of sockeye salmon in freshwater ecosystems is critical in sustaining adult returns. Thus, abundance estimates at each life-history stage are necessary to partition the relative influence of freshwater versus marine environments on total sockeye production. During 18-20 September 2002 hydroacoustic surveys were conducted on Skilak and Kenai Lakes using split-beam sonar. The population estimates for Skilak and Kenai Lakes were respectively 10,336,000 and 1,973,500 fish. In early September 2002, midwater trawl sampling was also conducted on both lakes to obtain information on age, weight and length (AWL). Age-0 (young-of-the-year) sockeye composed 67 % of the sampled fish in Skilak Lake. The mean weight and length of this cohort was 0.95 g and 43.9 mm. In Kenai Lake, age-0 fry accounted for 99 % of the sample and they had a mean length and weight of 51.8 mm and 1.5 g. Sockeye juveniles rearing in these glacially turbid lakes are some of the smallest when compared to other Alaskan glacial and non-glacial lakes. Size and condition of smolts are important integrators of abiotic and biotic factors imposed on rearing sockeye juveniles in freshwater lake ecosystems.

KEY WORDS: Alaska, Cook Inlet, Kenai River, fry, glacial lakes, hydroacoustics, salmon, sockeye, split-beam sonar

INTRODUCTION

Interannual variation in juvenile sockeye salmon, *Oncorhynchus nerka*, growth rates and abundance vary significantly both within and among systems throughout the Pacific Rim (Burgner 1987). Developing relationships between limnological conditions and sockeye productivity enhances our understanding of ecosystem processes and population dynamics. Such empirical models provide a useful tool for fishery management (Koenings and Burkett 1987, Hume et al 1996). For instance, it has been shown that recruitment of sockeye fry in Skilak Lake is tightly coupled with the abundance of cyclopoid copepods and the magnitude of glacial run-off (Edmundson et al. 2003). However, the ability to more accurately predict future fish stocks and resolve some of the uncertainty about what level of escapement will optimize production can be greatly enchanced by collection of long term juvenile and adult sockeye and limnological data sets.

In September 2002, the Alaska Department of Fish and Game (ADF&G) conducted its annual juvenile sockeye salmon population estimates along with age, weight and length (AWL) sampling on Skilak and Kenai lakes. These data are part of a long time series extending back to 1986 (DeCino 2001, DeCino and Degan 2000, Tarbox and King 1988a, 1988b, Tarbox, et. al. 1993, Tarbox and Brannian 1995, Tarbox et. al.1996). The objectives for the 2002 hydroacoustic population surveys were to (1) estimate juvenile salmon population size and (2) assess the pre-winter condition of sockeye juveniles. We used split-beam sonar and mid-water trawls to estimate the population abundance mean size at age and age composition of rearing sockeye juveniles in Skilak and Kenai lakes.

Description of Study Site

The Kenai River is located on the Kenai Peninsula in South-central Alaska (Figure 1). Within the Kenai River watershed, Skilak and Kenai lakes are the major nursery areas for sockeye salmon fry. The glacial waters of the Snow River feed into Kenai Lake, the outlet of which is the beginning of the Kenai River. Downstream from this lake, the Kenai River flows into Skilak Lake. The river channel below Skilak Lake, the larger of the two lakes, is of relatively low gradient and flows westerly into Upper Cook Inlet. Skilak lake has a surface area of 99km^2, mean depth of 73 m, and maximum depth of 160 m (Figure 1); Kenai Lake has a surface area of 55.9 km^2, mean depth of 91 m, and a maximum depth of 165 m (Figure 2).

METHODS

Hydroacoustic Surveys

We used a stratified-random sampling design for the hydroacoustic surveys to distribute sampling effort and provide an appropriate estimate of total fish abundance and variance. Each lake was divided into areas or sub-basins and survey transects were randomly selected within each area. The number of transects were chosen to reduce relative error to ~25% for Skilak Lake and 30% for Kenai Lake. The sample size was based on Tarbox et al (1996). In addition, transects across each lake were geo-referenced during the hydroacoustic survey (DeCino and Degan 2000). Because of the configuration of Skilak Lake transects perpendicular to shore were surveyed within three sub-basins (Figure 3). In Kenai Lake, transects were surveyed within five sub-basins (Figure 4). Juvenile sockeye salmon were sampled, acoustically, at night with a BioSonics DT-6000[1] split beam echosounder. A 6.6° circular split-beam transducer was mounted to a 1.5-m long aluminum sled. The transducer transmitted digital data via a 15-m long cable to the echosounder. The echosounder was connected to a laptop computer via pcmcia data connection. For geo-referenced transect routes a Garmin[1] GMAP model 175 global positioning system (GPS) was used.

Acoustic digital data were collected and stored on a laptop computer hard-drive. Configuration parameters were input into BioSonics[1] *Visual Acquisition* data collection software. Environmental variables (temperature) were measured with YSI[1] model 58 digital thermistor and input to the environmental variables of the program. Fish were acoustically sampled at 2 pings/sec, 0-51 m depth, 0.2 ms pulse width and a –65dB data threshold. Twelve-volt batteries powered the acoustic system and the laptop computer.

Transects were chosen based on a stratified random design (DeCino and Degan 2000, Tarbox et. al. 1996, Jolly and Hampton 1990, Figures 1 & 2). Transects were traversed at approximately 2m/s. The acoustic vessel (7.2 m long) was powered by two, two-stroke, outboard engines. The transducer/sled was attached to a cable, ("come-a-long"), connected to a boom and towed off the boat's starboard side approximately 1-m below the water surface.

Acoustic data were stored (hard-drive) and transported to the area office where they were uploaded into the Area office network for access by analysis programs. The acoustic data were edited by use of BioSonics[1] *Visual Analyzer* program. Acoustic data were first bottom edited to remove bottom echoes. After bottom editing was complete, individual target information was processed and saved for *in-situ* target strength and sigma (σ) the backscattering coefficient.

Target strength and σ computations were performed using a macro built by Aquacoustics Inc[1]. For each lake, this macro appended all transects and calculated *in-situ* target strengths and σ's from each detected target. Targets were filtered to include only those echoes near the beam center (0 to –4dB off axis). The entire lake average σ was input to BioSonics[1] *Visual Analyzer* program for echo-integration.

Fish density was estimated for each transect and expanded for each area from which they were collected. The echo integrator compiled data in 20 report sequences along each transect and sent outputs to computer files for further reduction and analysis. The total number of fish (N_{ij}) for area stratum i based on transects j was estimated across depth stratum k. N_{ij} consisted of an estimate of the number of fish detected by hydroacoustic gear in the mid-water (2-51 m) layer (M_{ij}) and an estimate of the number of fish in the surface layer (0-2 m). In order to estimate the number of fish unavailable to the hydroacoustic gear because of their location near the surface (S_{ij}), the fish density

[1] Use of a company name does not constitute endorsement by ADF&G.

in the upper stratum was assumed equal to the density in the first stratum echo integrated in the lake. That assumption is based on lake morphometry and percent volume sampled in post-processing analysis:

$$\hat{N}_{ij} = \hat{S}_{ij} + \hat{M}_{ij}$$

The mid-water component was estimated as

$$\hat{M}_{ij} = \sum_{k=1}^{K} a_i m_{ijk} ,$$

where a_i represented the surface area (m^2) of area stratum i which was estimated using a planimeter and USGS maps of Skilak and Kenai Lakes. The depth would be less than the maximum 51 m if the bottom was detected within depth stratum k anytime along a transect. The estimated mean fish density in area i depth k across transect j was m_{ijk} in number/m^2.

The estimated number of fish near the surface (0–2 m) in area i was

$$\hat{S}_{ij} = a_{is} m_{ij1} ,$$

where a_{is} was the estimated area (m^2) of the surface stratum (0–2 m), and m_{ij1} is two-fifths the mean fish density for in the first ensonified depth stratum (1–5 m below transducer) of transect j.

Fish abundance in area i (N_i) became the mean abundance estimated by each transect j, or

$$\hat{N}_i = J^{-1} \sum_{j=1}^{J} N_{ij} ,$$

and its variance was estimated as

$$v(\hat{N}_i) = \sum_{j=1}^{J} (\hat{N}_{ij} - \hat{N}_i)^2 (J - 1)^{-1} J^{-1} .$$

Total fish abundance (N) for each lake was estimated as the sum of the area estimates and the variance of N was estimated as the sum of the area variance estimates.

The abundance of juvenile sockeye salmon in each lake (N_s) was estimated as

$$\hat{N}_s = \hat{N}\hat{P} ,$$

where $\hat{P}$ is the estimated proportion of total fish targets that were juvenile sockeye salmon in the lake. Age-specific numbers of juvenile sockeye salmon (N_{sa}) were estimated as

$$\hat{N}_{sa} = \hat{N}\ \hat{p}_a,$$

where $\hat{P}_a$ is the estimated proportion of age-*a* sockeye salmon in the fish population.

Variance estimates were calculated as

$$v(\hat{N}_s)=\hat{N}^2 v(\hat{P})+\hat{P}^2 v(\hat{N})-v(\hat{P})v(\hat{N})$$

$$v(\hat{N}_{sa})=\hat{N}^2 v(\hat{P}_a)+\hat{P}_a^2 v(\hat{N})-v(\hat{P}_a)v(\hat{N})$$

Age, Weight, and Length (AWL) surveys

Mid-water trawl (tow netting) sampling was conducted in both lakes to determine species composition of the targets and age composition, wet weight (g), and fork length (mm) of juvenile sockeye. Sampling in Skilak Lake utilized a stratified cluster and stratified two-stage sampling technique (Scheaffer et al. 1986, Cochran 1977). Area and depth defined strata. Areas were the same as those used in the hydroacoustic sampling. Depth strata were developed to account for potential vertical variation in species and age composition. Three depth strata were defined: surface (0-10 m), mid-depth (15-25 m) and deep (30-40 m). Each tow was defined as a primary sampling unit and a minimum of three tows were conducted in each stratum. All fish captured in each tow were identified to species. A proportionate subsample of sockeye was collected from each tow to estimate age composition and average length and weight.

In Kenai Lake, the same stratified random sampling technique was used (Scheaffer et al. 1986, Cochran 1977). However, three areas and two depth intervals were defined. The three sampling areas consisted of area one (identical to the hydroacoustic area one), area two (combining hydroacoustic areas two and three) and area three (combining hydroacoustic areas four and five). Two depth strata were defined: surface (0-10 m) and mid-depth (15-25 m).

All captured fish were enumerated, identified, and preserved in 10% formalin. In the laboratory juvenile sockeye salmon were measured to the nearest millimeter (fork length), weighed (wet) to the nearest 0.1 g, and the age determined from scale samples using criteria outlined by Mosher (1969).

RESULTS

Skilak Lake

A total of 21,135 echoes (Appendix Table A1) were used to estimate mean target strength of -53.2 dB with a standard deviation (SD) of 4.05 dB. The mean σ used for echo integration equaled 7.31 X 10^{-6} with a SD of 1.65 X 10^{-5} (Table 1). As a result, the estimated fish population was approximately 10,336,000 with a standard error (SE) of about 1,435,000 fish. Of the estimated population of juvenile sockeye salmon approximately 45 percent were detected in Area 1 (Table 2, Figure 3). In addition, the largest portion of juvenile sockeye salmon not available to hydroacoustic sampling techniques (estimated in the upper 2 m of the water column) were detected in Area 1 (Table 2). Skilak Lake's total contribution of fish in the upper 2 m was approximately 532,200 fish.

From the tow-net survey, 943 total fish were captured of which 924 fish or 98.0 % (SE = 0.003 %) were juvenile sockeye salmon. Nine hundred six juvenile sockeye were subsampled for age, wet weight, and fork length (AWL). Of the total sockeye captured, age-0 juvenile sockeye accounted for 67 % (SE = 0.047 %). The remaining 33 % (SE = 0.047 %) were apportioned to age-1 fish. Therefore, approximately 6,802,821 (SE = 1,057,918) and 1,057,918 (SE = 663,502) fish were aged 0 and 1+ years, respectively (Table 3). Age-0 juvenile sockeye salmon had an average weight of 0.95 g (SE = 0.02 g) with an average length of 43.9 mm (SE = 0.22 mm). The age-1 juvenile sockeye mean weight of 2.56 g (SE = 0.03 g) and a mean length were 62.3 mm (SE = 0.22 mm, Table 4, Figure 3).

Kenai Lake

A total of 9,349 echoes (Appendix Table A2) were used to estimate mean target strength in Kenai Lake. The mean target strength was –54.92 dB with a SD of 4.27 dB. The mean σ was 5.25 X 10^{-6} with a SD of 6.13 X 10^{-6}. This σ resulted in a population estimate of approximately 1,973,500 (SE = 194,452) fish. Of the 1,973,500 fish, approximately 110,600 fish were estimated to be in the lake surface layer (upper 2-m) not sampled by the hydroacoustic gear (Table 2). The greatest proportion of fish was located in area's four and five with the largest density in area 4 (Table 2).

From the mid-water trawl sampling conducted in Kenai Lake, the proportion of juvenile sockeye salmon accounted for 99.5 % (SE = 0.62 %) of the catch. This proportion resulted in a population estimate of approximately 1,963,168 (SE = 194,452) sockeye salmon. Of the apportioned juvenile sockeye, 99.1 % (SE = 0.24 %) were age-0 which accounted for approximately 1,945,452 (SE = 192,797) fish (Table 3). The mean age-0 fish weighed 1.53 g (SE = 0.02 g) and were 51.8 mm (SE = 0.24 mm) long. The remaining age-1 fish population was approximately 17,221 fish (SE = 5,011). Only six age-1 fish were captured in the midwater trawl for an average length of 64.5 mm (SE = 2.23) and weight of 3.03 g (SE = 0.32, Table 4, Figure 5).

Juvenile sockeye salmon in Kenai Lake were both significantly longer (F = 576.8, p = 0.00) and heavier (F = 457.4, p = 0.00) than the Skilak Lake age 0 cohort. Accordingly the acoustic sizes of juvenile sockeye salmon was not consistent with sizes of fish sampled from mid-water trawls. That is, fish targets in Kenai Lake had a significantly smaller target strength (F = 1179.6, p = 0.00) than targets in Skilak lake (Table 1, Figure 6).

DISCUSSION

Fry abundance estimates, mean size and condition and age composition derived from acoustic and midwater trawl surveys are important data used to predict adult sockeye salmon returns to the Kenai River system. For example, Edmundson et al (2003) suggested the size of fry in the fall is strongly influenced by density dependent processes within these lakes. Particularly, heavy copepod predation by fry in a given year affects copepod biomass the following spring, which can negatively affect fry and adult recruitment. Understanding the interaction between juvenile salmon populations and their food resources is critical to setting biological escapement goals (BEGs) and forecasting adult returns.

In September 2002, we used a 200 kHz split-beam sonar system to estimate juvenile sockeye salmon abundance in Kenai and Skilak Lakes using echo integration. The population estimate of juvenile sockeye salmon for both systems ranked as the eleventh largest since 1986. For Skilak Lake the 2002 population estimate was approximately one-half the size of the 2001 population estimate. The 2002 population estimate falls between the 1987 and 1994 population estimates (Figure 7).

The juvenile sockeye salmon population estimate in Skilak Lake followed a similar trend since 1986 in that, there was a greater abundance of fry in Skilak Lake compared to Kenai Lake. The 2002 Skilak Lake population of juvenile sockeye salmon is the tenth highest estimate since 1986 (Figure 4). For comparison, the highest population estimate occurred in 1993, and consisted of approximately 33 million fry (Tarbox et al 1996). The lowest population estimate (1996) totaled 5.2 million fish. The average population estimates since 1986 is equal to 16.0 million fish with a SD of 8.59 million fish. This estimate is about 6 million less than the historical average.

The 2002 Kenai Lake population estimate of 1.9 million fish is eleventh highest since inception of acoustic estimates starting in 1986 (Figure 7). Juvenile sockeye salmon estimates range from 768,000 in 1996 to 6.2 million in 1988 (Tarbox et al 1996). The average population since 1986 is 2.70 million fish with a SD of 1.42 million. The population of Kenai Lake is about 800,000 fish below the historical mean population estimates.

Target strengths of the juvenile sockeye salmon measured with the split-beam transducer were within reported ranges derived using a dual-beam transducer from previous hydroacoustic surveys (see Tarbox et al. 1996). Likewise, estimates of mean juvenile sockeye salmon size followed historical between-lake trends. Specifically, Kenai Lake, on average, produced larger fry compared with Skilak Lake. This relationship is opposite of what we have seen for the previous three years. However, target strengths were within the reported historical values of each lake. Nonetheless, our results from townetting gave a confounding picture when compared with acoustic-generated size data. Mid-water trawls for these systems have been deployed during daylight hours when fish have been observed, acoustically, to school more tightly (Tarbox personal communication) and the possibility of catching smaller fish could occur.

In addition to potential errors associated with day mid-water trawls, tilt angle of fish could affect the echo of a reflected target. Reflected waves tend to cancel from the returning echo when the angle of the fish is not perpendicular to transducer face (see figure 6.16 in MacLennan and Simmonds 1992) and thus reduces target strength. This could explain the reduced target strength in Kenai Lake this season because the acoustic survey was done when windy (15-20 knot) conditions existed compared to Skilak Lake when conditions were calm.

In order to minimize bias in sampling error with respect to target strength measurements and townetting data the researcher should do them simultaneously. For example, during night acoustic surveys the survey vessel should direct the catcher vessel where to fish for associated targets. The catcher vessel should run a capture course that is geo-referenced to compare with similar data (depth, latitude, longitude, and target strength) generated by the acoustic vessel. By doing this the researcher will be able to directly compare the acoustic target strengths to the netted targets biological size.

In September 2002, we encountered the second highest percentage of holdovers (i.e., age-1 fry) since the beginning of hydroacoustic surveys and midwater trawl sampling in Skilak Lake. Historically age-0 sockeye account for 90% of the total population estimate, but in 2002 the age-0 cohort composed only 66% of the total fry population. We do not believe this to be the result of sampling error because age-1 juvenile sockeye were detected in greater abundance throughout Skilak Lake. Other researchers have shown that large numbers of sockeye fry holdover for an additional year of lake rearing if poor environmental conditions or intraspecific competition occur and they do not reach a minimum threshold size prior to migrating out to sea (Koenings and Burkett 1987; Kyle et al. 1988; Koenings and Kyle 1997).

Digital split-beam acoustic technology (with geo-referencing of the data) provides the biologist with a means to construct a database linking morphometric and biological features. In addition, this information is critical for fisheries management because it partitions the relative influence of freshwater and marine environments on adult recruitment. The magnitude of adult returns to the Kenai River is not simply a function of the number of parental spawners but also of rearing conditions during the juvenile lifestage. This technology, is state-of-the art and yields not only basic biotic inventory, but coupled with spawner and smolt estimates these data make for more sound projections of the size of future fish stocks and provide important information for determining sound ecological BEG's.

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Table 1. Target strength (dB) and sigma (σ) the mean backscattering coefficient for echo integration used to estimate population of juvenile sockeye salmon *O. nerka.*

Lake	N	Target Strength (dB)	σ
Skilak	22,135	-53.18(4.05)	7.31×10^{-6} (1.65×10^{-5})
Kenai	9,349	-54.92(4.27)	5.25×10^{-6} (6.13×10^{-6})

Table 2. Estimated number of fish in Skilak and Kenai Lakes, Alaska in September 2002.

			Estimated Number of Fish				
Lake	Area	Transect	Surface	Midwater	Total	Area Mean	Variance
Skilak	1	1	1.3385E+05	6.6751E+06	6.8090E+06		
		2	5.1471E+04	3.2045E+06	3.2560E+06		
		3	4.7719E+05	4.8208E+06	5.2980E+06	4.6069E+06	8.7034E+11
		4	2.2573E+05	6.5224E+06	6.7481E+06		
		5	8.0458E+05	3.9088E+06	4.7134E+06		
		6	1.4007E+04	8.0313E+05	8.1714E+05		
	2	1	2.2280E+04	1.4918E+06	1.5141E+06		
		2	7.3961E+04	2.4760E+06	2.5500E+06	3.3419E+06	1.1655E+12
		3	1.3690E+05	2.7001E+06	2.8370E+06		
		4	1.9605E+05	6.2704E+06	6.4664E+06		
	3	1	2.7308E+05	1.8290E+06	2.1021E+06		
		2	1.9374E+05	2.2395E+06	2.4332E+06	2.3870E+06	2.2617E+10
		3	6.1372E+04	2.7274E+06	2.7888E+06		
		4	3.3533E+04	2.1902E+06	2.2238E+06		
	TOTAL					1.0336E+07	2.0584E+12
Kenai	1	1	0.0000E+00	8.1273E+04	8.1273E+04		
		2	3.9332E+03	9.7220E+04	1.0115E+05		
		3	2.2550E+04	1.6699E+05	1.8953E+05	9.0523E+04	5.1566E+08
		4	0.0000E+00	4.6554E+04	4.6554E+04		
		5	1.3276E+04	8.0203E+04	9.3479E+04		
		6	0.0000E+00	3.1144E+04	3.1144E+04		
	2	1	0.0000E+00	2.4786E+05	2.4786E+05		
		2	0.0000E+00	2.8681E+05	2.8681E+05		
		3	0.0000E+00	4.2006E+05	4.2006E+05	3.7826E+05	6.3765E+09
		4	1.1592E+05	5.5755E+05	6.7347E+05		
		5	0.0000E+00	2.6308E+05	2.6308E+05		
	3	1	8.2210E+04	3.2610E+05	4.0831E+05		
		2	2.5289E+03	1.1377E+05	1.1630E+05		
		3	9.4477E+03	1.1475E+05	1.2420E+05	2.7746E+05	4.4411E+09
		4	5.5590E+03	4.1561E+05	4.2117E+05		
		5	1.6370E+04	3.0094E+05	3.1731E+05		
	4	1	2.6075E+04	5.6625E+05	5.9232E+05		
		2	6.9632E+04	1.1669E+06	1.2366E+06		
		3	7.8775E+03	5.3269E+05	5.4057E+05	6.8565E+05	2.0209E+10
		4	1.5115E+03	6.3303E+05	6.3454E+05		
		5	2.5930E+03	4.2167E+05	4.2426E+05		
	5	1	5.9071E+04	3.2371E+05	3.8278E+05		
		2	2.8191E+03	3.2608E+05	3.2890E+05		
		3	2.5890E+04	5.1695E+05	5.4284E+05		
		4	1.6419E+05	8.0859E+05	9.7277E+05	5.4164E+05	6.5200E+09
		5	0.0000E+00	4.7622E+05	4.7622E+05		
		6	0.0000E+00	4.6282E+05	4.6282E+05		
		7	0.0000E+00	6.2513E+05	6.2513E+05		
	TOTAL					1.9735E+06	3.8063E+10
	TOTAL FOR BOTH LAKES					1.2309E+07	2.0965E+12

Table 3. Estimated fish population and contribution of age-0 and age-1 sockeye salmon to the total fish population in Kenai and Skilak Lakes, Alaska, night surveys. September 2002.

Lake	Estimated Total Fish	Standard Error (SE)	Estimated Juvenile Sockeye	Standard Error (SE)	% Age-0	Total Age-0	Standard Error (SE)	% Age-1	Total Age-1	Standard Error (SE)
Skilak	10,336,000	1,434,713	10,127,745	1,406,130	65.8	6,802,821	1,057,918	32.2	3,324,924	663,502
Kenai	1,973,500	195,097	1,963,168	194,452	98.6	1,945,871	192,797	0.9	17,221	5,011
Total	12,309,500	1,447,917	12,090,913	1,419,511		8,748,692	1,350,404		3,342,145	663,521
Variance	2.1×10^{12}		2.0×10^{12}			1.2×10^{12}			4.4×10^{11}	

Table 4. Age, weight and length of juvenile sockeye salmon from midwater trawl surveys September 2002.

	Age-0			Age-1		
Lake	n	mean l (mm)	mean wt (g)	n	mean l (mm)	mean wt (g)
Skilak	608	43.9 (0.24)	0.95 (0.02)	155	62.3 (0.22)	2.56 (0.03)
Kenai	564	51.8 (0.23)	1.53 (0.02)	6	64.5 (1.57)	3.03 (0.21)

Standard Errors (SE) are in parenthesis

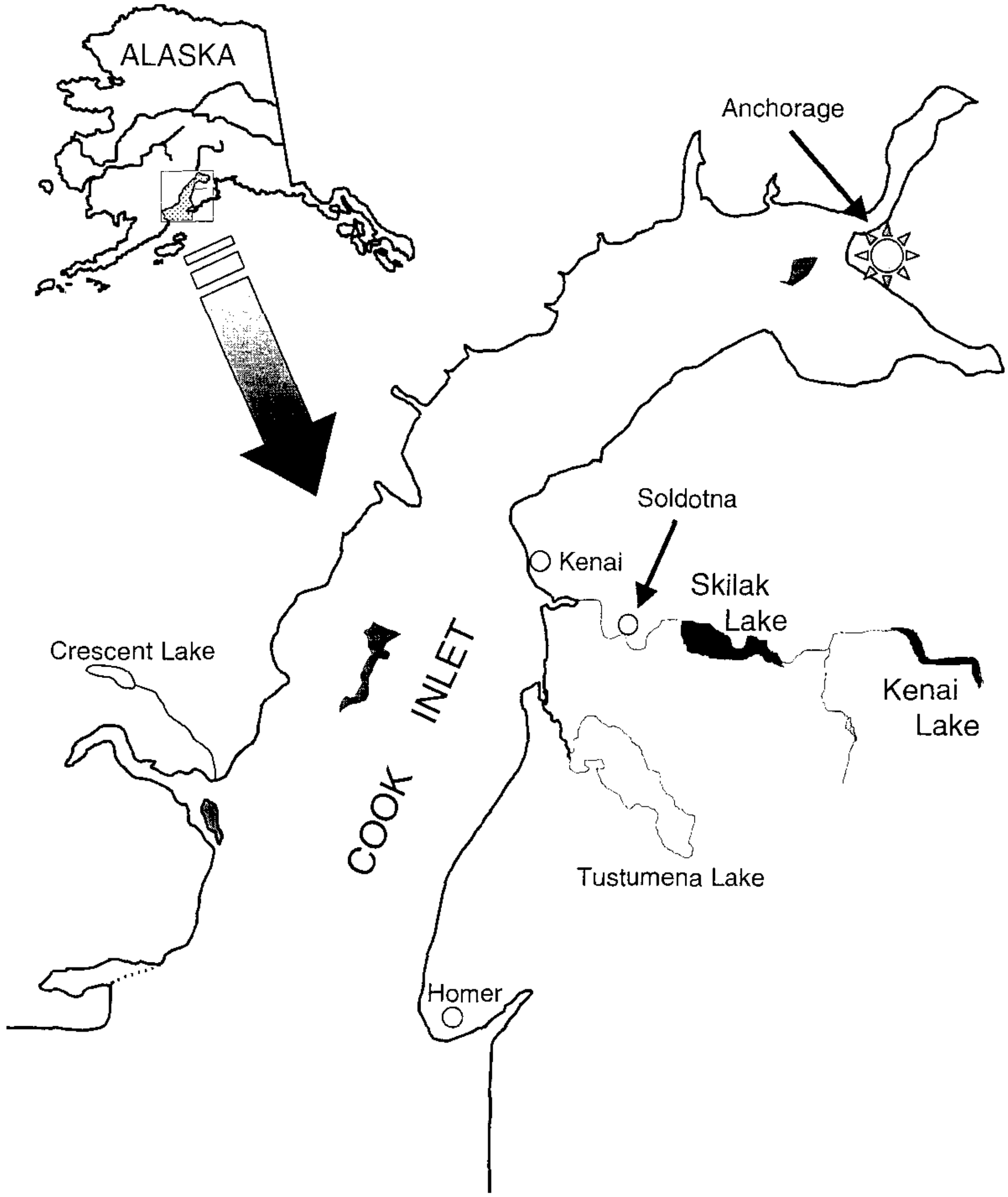

Figure 1. Geographic location of Skilak Lake in relation to the Kenai River system and Cook Inlet, Alaska.

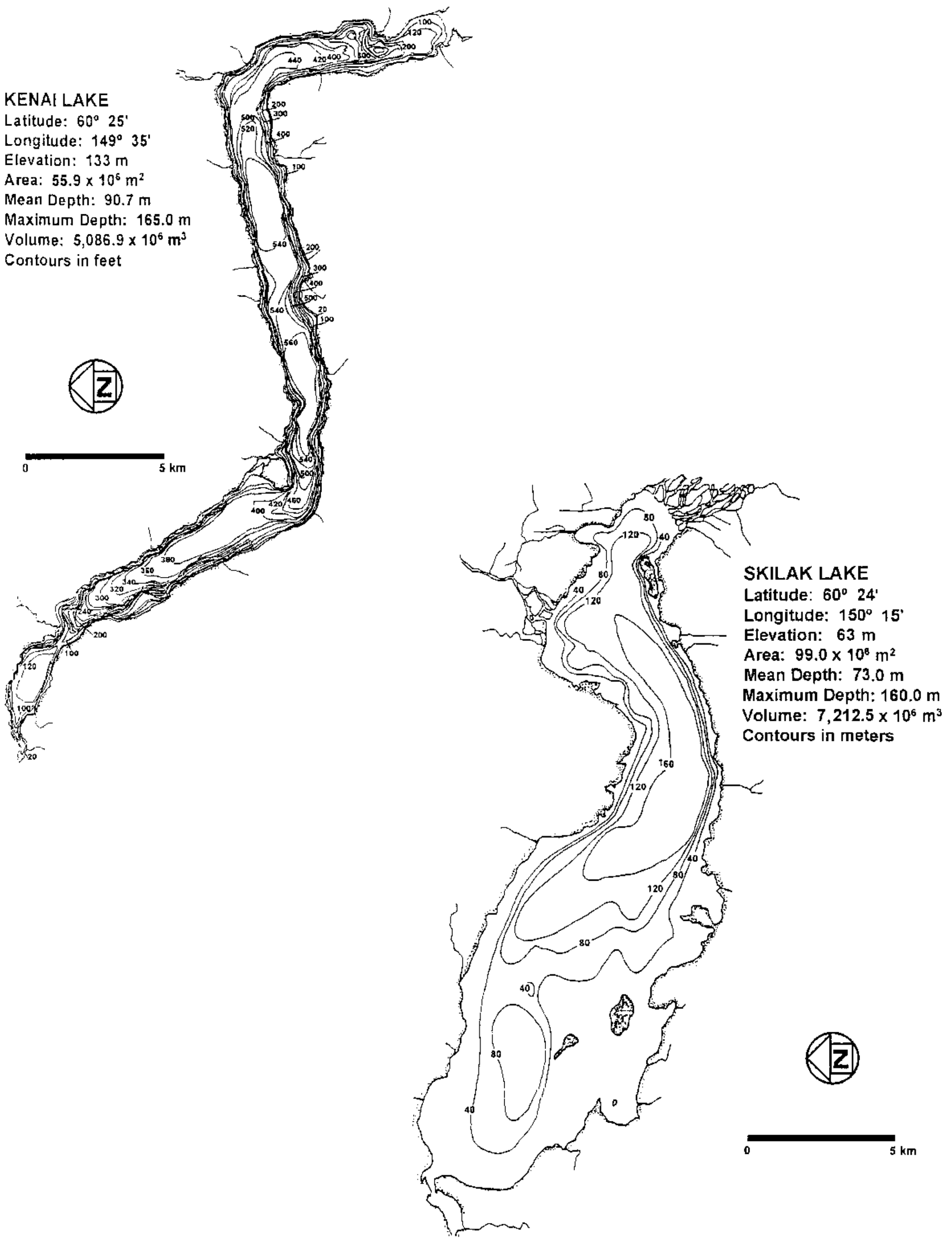

Figure 2. Bathymetric maps of Kenai and Skilak Lakes with morphometric data.

Skilak Lake Transects September 18, 2002

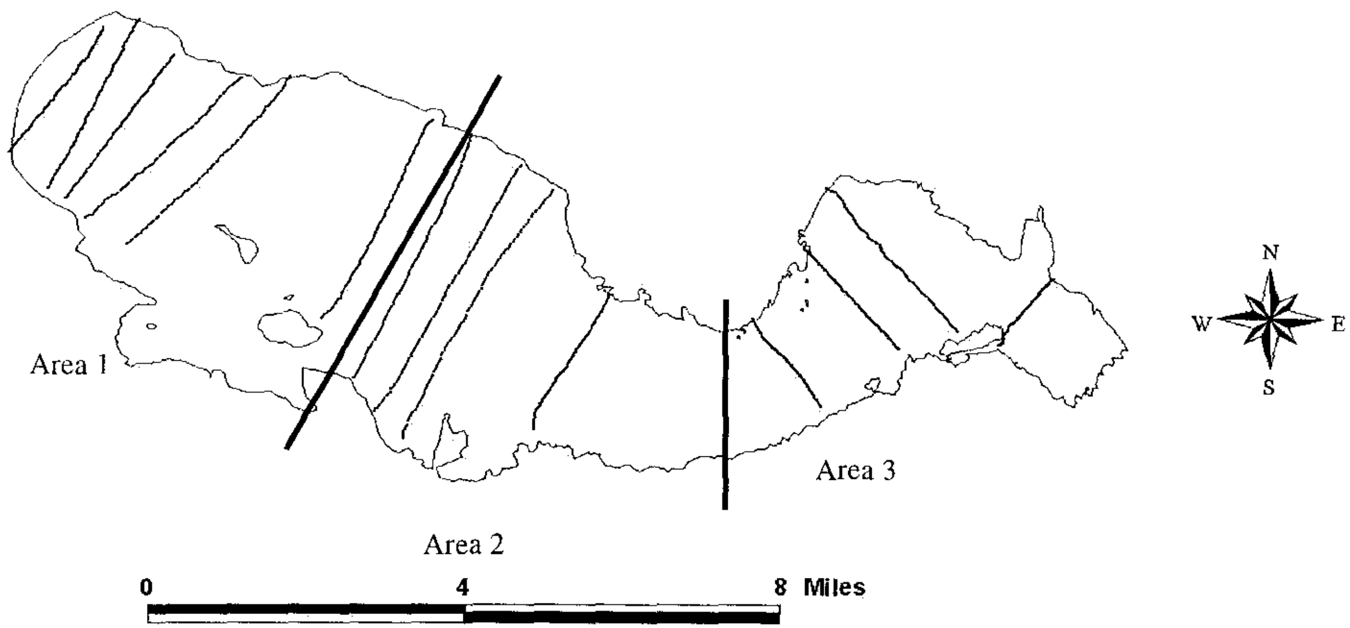

Figure 3. Skilake Lake transects run on September 18 and 19, 2002

Kenai Lake Transects September 19, 2002

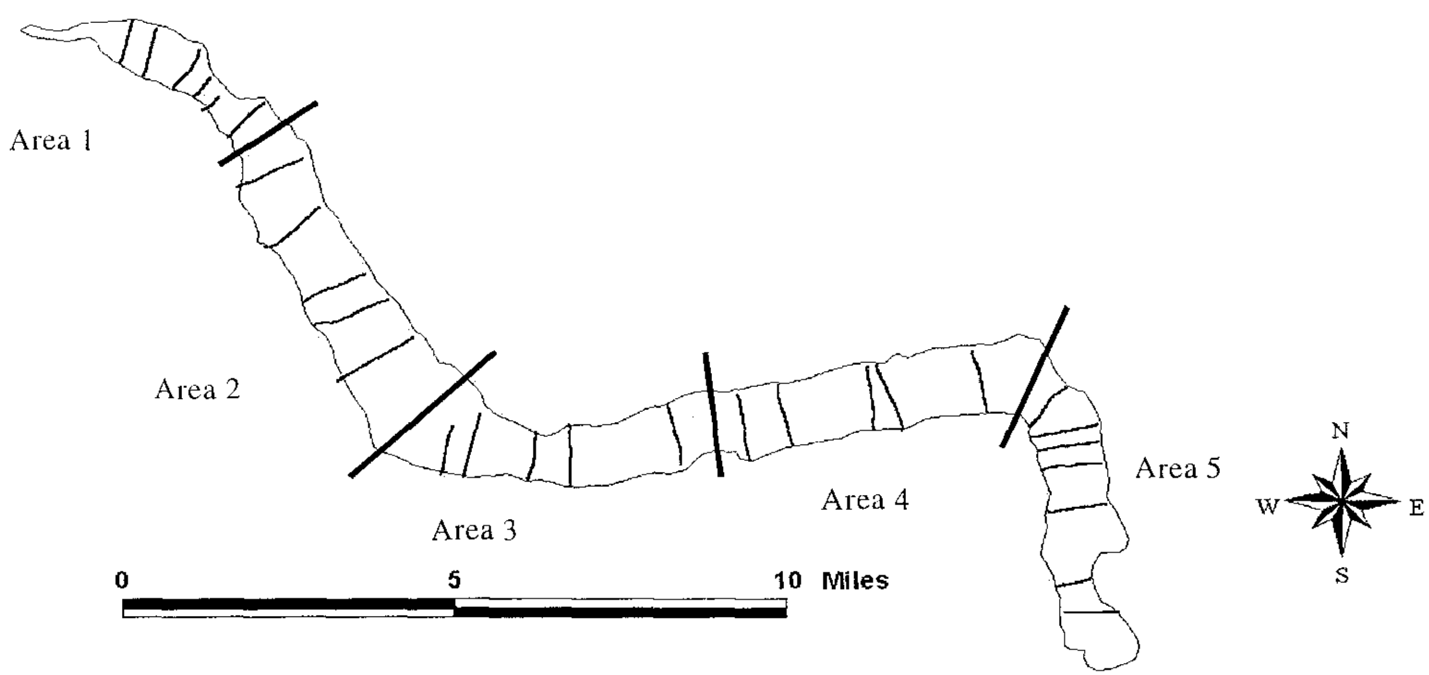

Figure 4. Transects run in Kenai Lake on Sept 19 and 20, 2002.

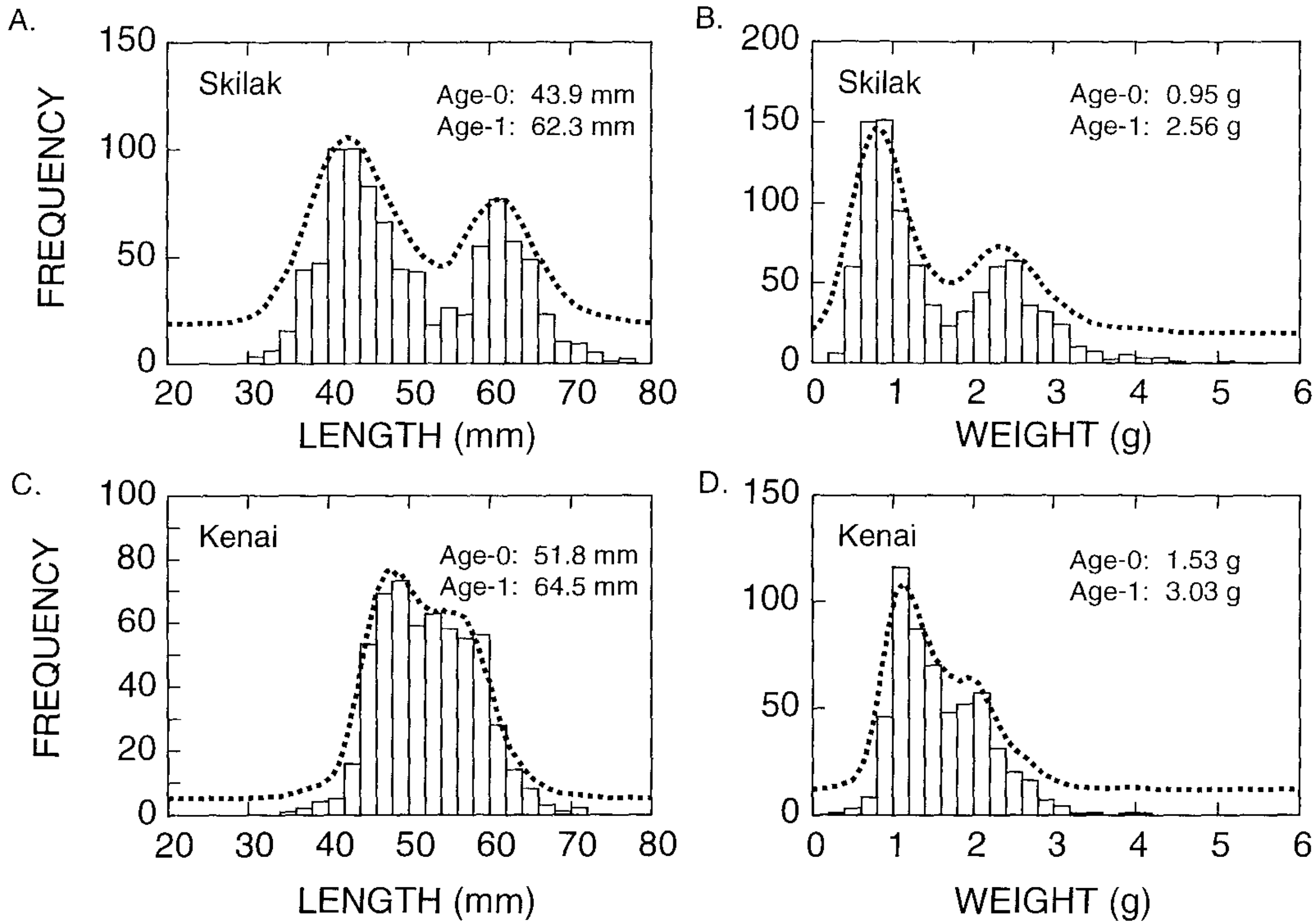

Figure 5. Size distribution of sockeye fry collected from (A-B) Skilak and (C-D) Kenai lakes in September 2002. Also shown are the mean sizes for the age-0 and age-1 cohorts. Dashed line is the non-parametric(kernel) density function.

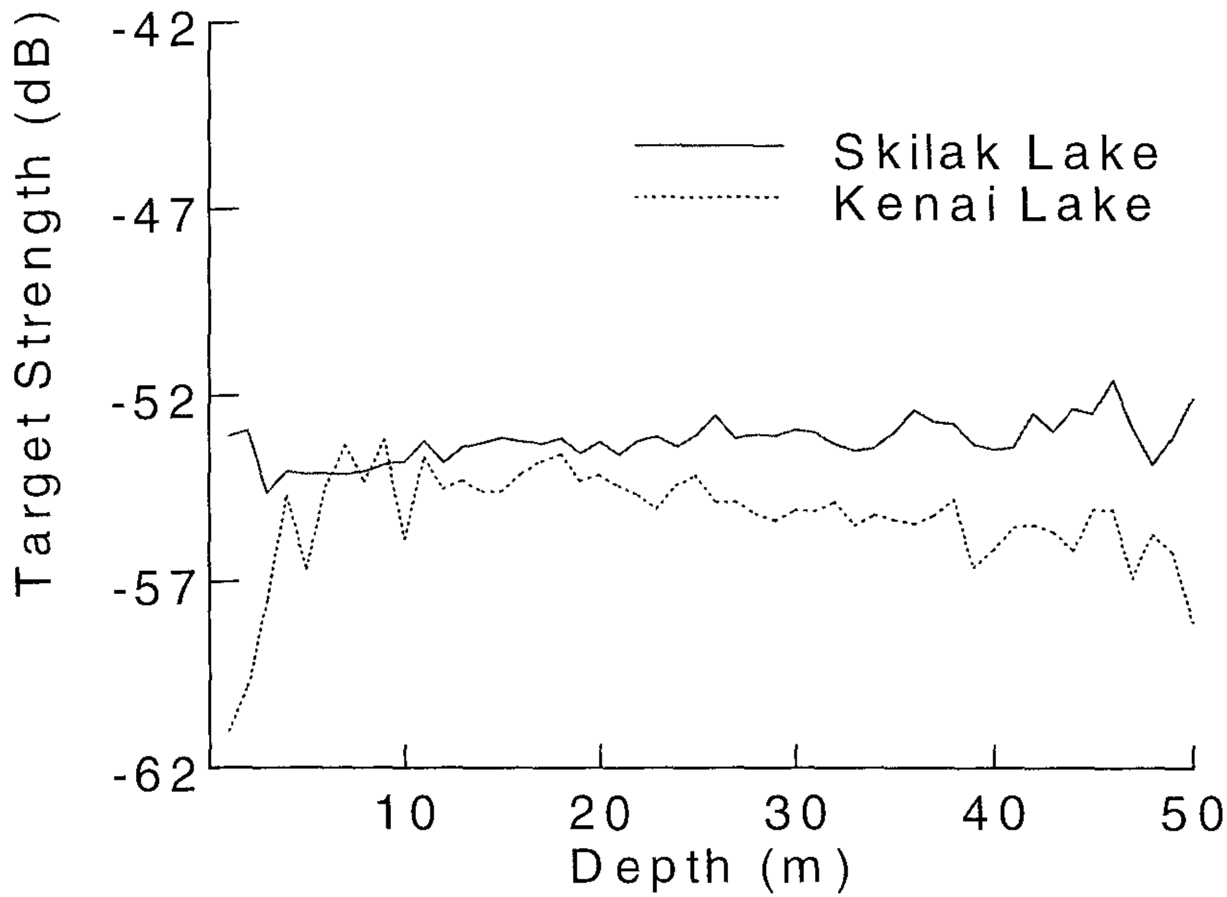

Figure 6. Target strength (dB) vs. depth for Kenai and Skilak lakes hydroacoustic surveys in September 2002.

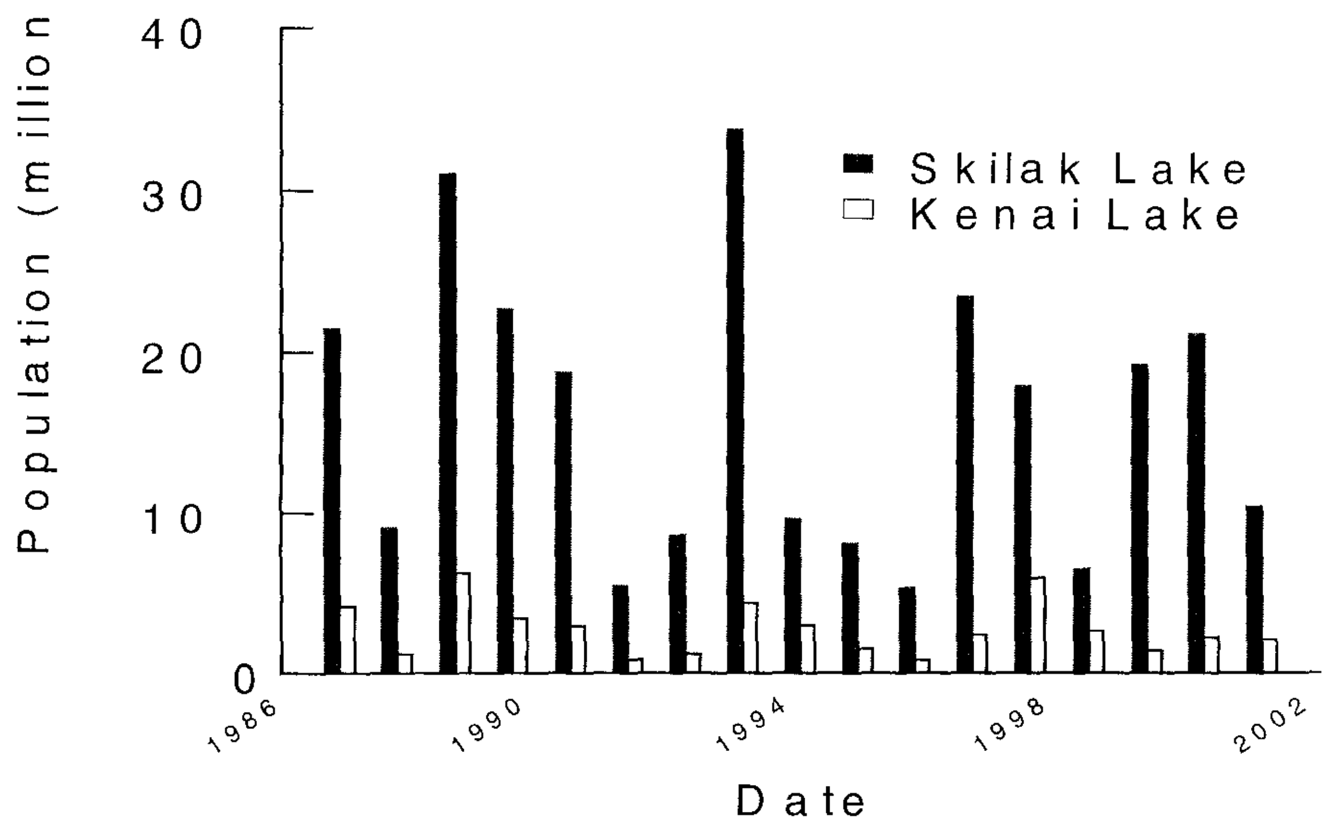

Figure 7. Historical population estimates of juvenile sockeye salmon in Kenai and Skilak lakes.

Appendix A.1. Mean σ for September 2002 hydroacoustic survey in Skilak Lake.

Skilak Strata	Number	σ	Mean σ / Depth σ
1 – 6 m	225	6.46E-06	0.98
6 – 11 m	1240	6.67E-06	0.99
11 – 16 m	2411	7.15E-06	0.99
16 – 21 m	3782	7.11E-06	0.99
21 – 26 m	4569	7.01E-06	0.99
26 – 31 m	4290	7.51E-06	1.00
31 – 36 m	2945	6.62E-06	0.99
36 – 41 m	1587	7.31E-06	0.99
41 – 46 m	677	1.25E-05	1.04
46 – 51 m	109	1.03E-05	1.02
Grand Total	22135	7.31E-06	1.00

Appendix A. 2. Mean σ for September 2002 hydroacoustic survey in Kenai Lake.

Kenai Strata	Number	σ	Mean σ / Depth σ
1 – 6 m	10	2.17E-06	0.93
6 – 11 m	82	6.09E-06	1.01
11 – 16 m	281	6.08E-06	1.01
16 – 21 m	791	6.47E-06	1.02
21 – 26 m	1659	5.64E-06	1.01
26 – 31 m	2429	5.42E-06	1.00
31 – 36 m	2857	4.89E-06	0.99
36 – 41 m	872	4.33E-06	0.98
41 – 46 m	289	4.06E-06	0.98
46 – 51 m	79	3.76E-06	0.97
Grand Total	9349	5.25E-06	1.00